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Guidelines for Characterization of Repair Materials

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JAMS 2018 Technical Review
May 23-24, 2018

Guidelines for Characterization of Repair Materials

- Motivation and Key Issues
  - As commercial aircraft make greater use of composites in airframes and engines, there is an increased need for new research and development on composite repair.
  - The General Accounting Office (GAO) has expressed concerns over accelerating use of composites in aircraft structures, specifically citing the “limited standardization of composite materials and repair techniques”.
  - Variability and lack of certainty about repair quality remain significant issues for the aerospace industry.
  - Substantial data are necessary to design and substantiate a repair that meets all requirements of the original design.
  - Challenges are still encountered showing equivalence within the repair application accounting for the process variation and exact repair process utilized for the repair.

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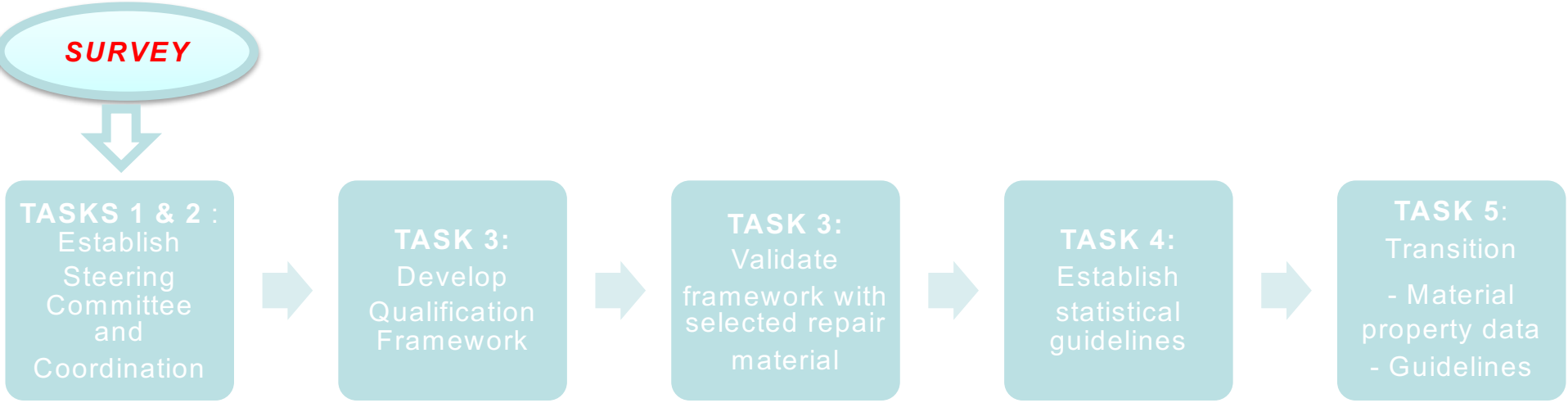
Development of Repair Qualification Program

- Technical Monitor: Ahmet Oztekin
- NIAR Contacts: John Tomblin, Rachael Andrulonis, Royal Lovingfoss, Jeff Gilchrist

- Objectives
  - Primary objective: To develop a framework for the qualification of new and innovative material platforms for composite repair including guidelines and recommendations for their characterization, testing, design and utilization.
  - Secondary objective: To transition the test data and guidelines generated in this program into shared databases, such as CMH-17.

Technical Approach

- Develop a framework to advance repair materials into the aerospace industry.
- Utilize the experience and framework of the NCAMP composite program as an example of process sensitive material characterization.
- Assess the validity with equivalency testing.



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Survey Results: Industry Needs

- Results showed a strong need for the standardization of composite repair.
- The need for new materials
- Data
- Better documentation, training, and information to be included in the repair manuals.
- Several recommendations for improvements to existing repair procedures were suggested including:
  - More closely following current procedures, supplying build data, better NDT procedures and standards, better surface preparation and inspection procedures, more comprehensive process details, repair technology transfer, repairmen minimum training requirements and more extensive use of travelers.

Task 1: Steering Committee

- Steering committee been formed with interested individuals
- Kick-off meeting was held in January 2017
- Periodic teleconferences or updates as needed
- On-line Portal
- Collaboration with CMH-17

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Task 2: Coordination

- Coordinate efforts with other groups and national initiatives working towards characterization, standardization and certification of composite repair materials.
  - *SAE Commercial Aircraft Composite Repair Committee (CACRC)*–

    Repair Materials Task Group – Develop repair material specifications in support of commercial airplane bonded repairs
    - Presented at June 2017 CACRC meeting
    - Repair Materials Task Group – All members invited to join Steering Committee
  - *Composite Material Repair* – DoD group focused on composite repair state of the art and challenges in military applications
    - Ongoing coordination with Air Force and Navy efforts on repair processing and testing
    - Presented at Composite Maintainers TIMS Conference – August 2017, attending June 2018 conference

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Task 3: Development of Qualification Program

GOAL: Generate the framework for a qualification test program including material and process specifications, test matrices, and documentation requirements.

Objectives:

- Select repair material and process to initially develop this framework. The material was selected with input from the survey and steering committee.
- Address quality aspects of the repair material manufacturing process and the framework for a quality assurance program.
- Draft material and process specifications for selected material.
- Develop a test matrix including required physical and mechanical data tailored to repair materials.
- Generate substantial mechanical property test data necessary for development of statistical guidelines using accepted test standards for the selected material.

Material Selection

- Out-of-autoclave prepreg material
  - Resin system: 5320-1
  - Fiber form: T650 PW
  - Baseline data approved through CMH-17
  - Currently included in Revision H of CMH-17 (being prepared for publication)
  - Spec being converted to SAE spec through P-17

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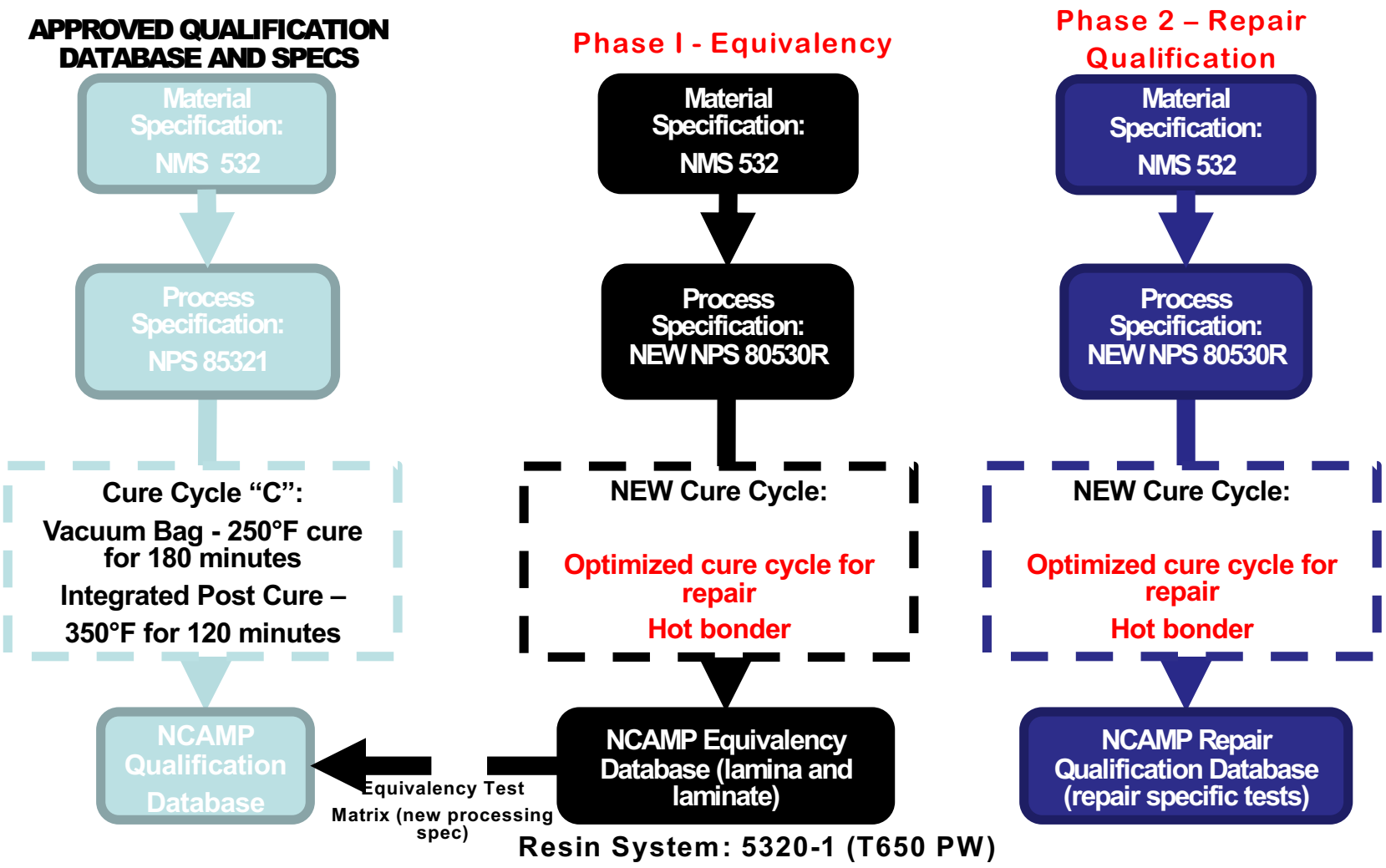
Equivalency and Qualification Test Plan



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Project Updates - Overview

- **Material**: Order was placed with Solvay in August
  - Prepreg - Material was delivered in November, batches 2 and 3 were incomplete – additional batches arrived in May
  - Adhesive – FM300-2 (delivered in April) – Solvay Audit in February
- **Test Plan (including matrix)**: Complete – on Portal
- **Material Spec**: NMS 532 (already approved)
- **Process Spec**: Initial release – on Portal
- **Qualification Testing**: Builds for equivalency are ongoing this month
- **Trials**: Repair flex trials took place over the last 4 months

New Process Specification (NPS 80530R)

- Parent panels for repair test – original cure cycle (NPS 85321)
- Process spec includes details on preparation of parent laminate, repair fabrication, bagging procedure, hot bonder use in cure
- Cure cycle
  - Modified to use hot bonder
  - New bagging sequence
- Quality Assurance
  - In process monitoring data

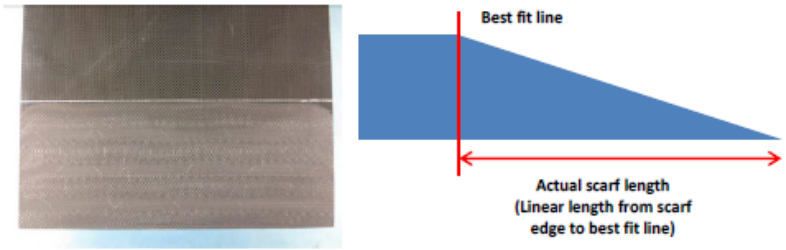

Figure 1. Sample scarfed panels

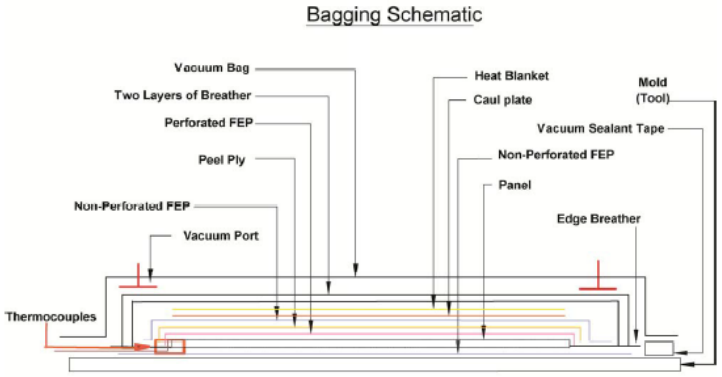

Figure 3. Bagging Technique for 5320-1 Repair Panels

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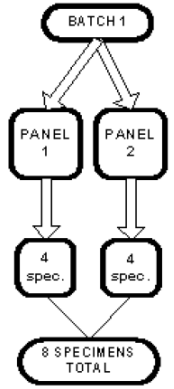
Equivalency Test Matrix – Lamina

QUALIFICATION REQUIREMENTS	Layup	TEST METHOD	Proposed Testing									TOTAL QTY
			DRY Conditioning						WET Conditioning			
			-65F			RTD			250F			
5320-1 T650 3K PW Material**	**Non-Repair Lamina Tests for Equivalency**											
Tensile Properties			BATCH			BATCH			BATCH			
Young's Modulus		ASTM D3039	I	II	III	I	II	III	I	II	III	
Ultimate Tensile Strength	[0]15		8			8			8			24
Poisson Ratio	[90]15		8			8			8			24
Compressive Properties												
Compressive Stregnth	[0]15	ASTM D6641	I	II	III	I	II	III	I	II	III	
Compressive Modulus	[90]15		8			8			8			24
			8			8			8			24
In-Plane Shear												
Strength	[+/-45]3S	ASTM D3518	I	II	III	I	II	III	I	II	III	
Modulus			8			8			8			24
Short Beam												
Strength	[0]32	ASTM D2344	I	II	III	I	II	III	I	II	III	
			8			8			8			24

Material Batch

Panel Manufacturing & Independent Cure Process

Number of Specimens Required per Test Method & Environment



Note ** - These tests are at the equivalency level only. They will be used to show that the new repair process gives data equivalent to the parent qualification.

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Equivalency Test Matrix - Laminate

QUALIFICATION REQUIREMENTS	Layup	TEST METHOD	Proposed Testing									TOTAL QTY
			DRY Conditioning						WET Conditioning			
			-65F			RTD			250F			
5320-1 T650 3K PW Material**	**Non-Repair Laminate Tests for Equivalency**											
Open Hole Tension		D5766										
			I	II	III	I	II	III	I	II	III	
Strength [45/0/-45/90]2S	(25/50/25)					8			8			16
Open Hole Compression		D6484										
			I	II	III	I	II	III	I	II	III	
Strength [45/0/-45/90/45/0/-45/90/-45/90]S	(25/50/25)					8			8			16
Compression After Impact		ASTM D7136& D7137										
			I	II	III	I	II	III	I	II	III	
Strength [45/0/-45/90/45/0/-45/90/-45/90]S	(25/50/25)					8			8			16

Note ** - These tests are at the equivalency level only. They will be used to show that the new repair process gives data equivalent to the parent qualification.

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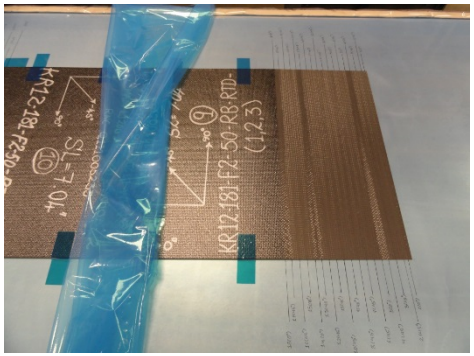
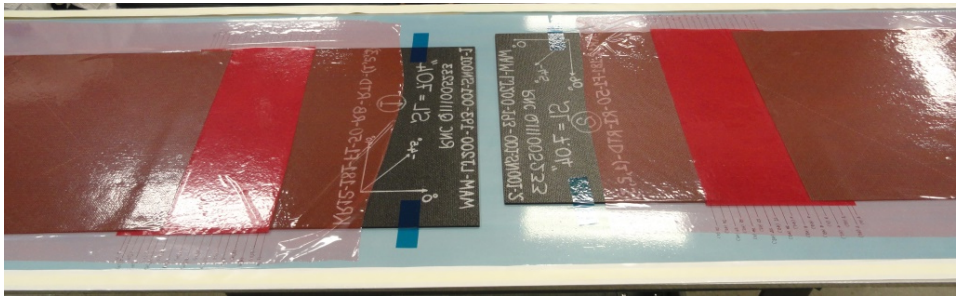
Parent Laminate Scarfed



Parent laminate panel scarfed, taped to tool and repair alignment lines have been marked with the appropriate direction of the ply designated.

Once alignment marks are applied, the scarf surface is cleaned and the film adhesive is applied



4 layers of the repair have been applied and the panel was then debulked. Separator film is applied to protect the prepreg and adhesive from contaminates.

Outcome of the debulk process.

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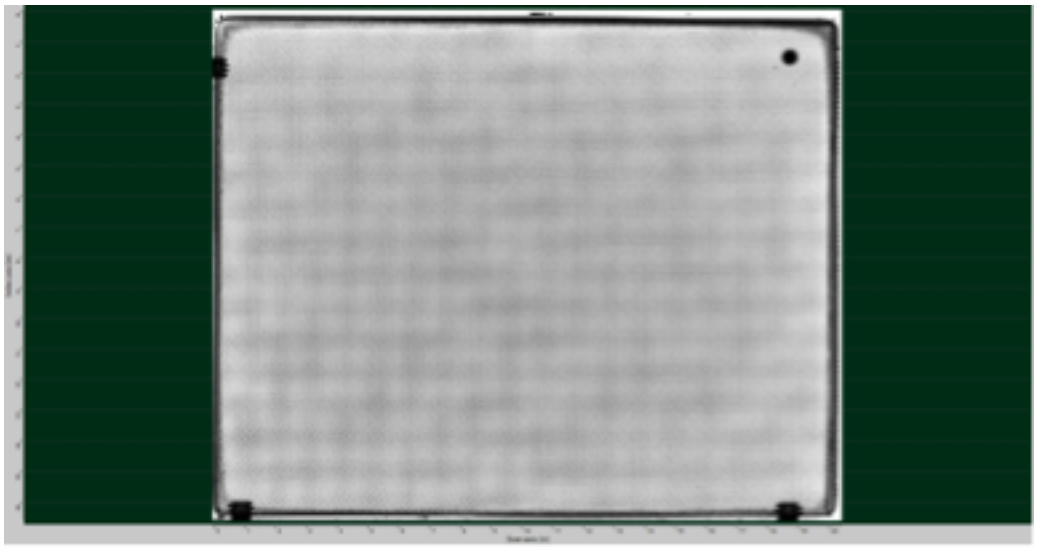
Laminate Flex Repair – Proof of Concept

- **Background**: Feasibility and development of quality laminate flex repair data was questioned by the Industry Steering Committee.
- **Objective** – Conduct a proof of concept flex test
  - Lay-up the parent flex panel per NPS 85321 in an out of autoclave cure
  - Continuous scarf the panel to a 50:1 ratio
  - Lay-up the repair per NPS 80530R on the parent panel using FM300-2 and cure using a hot bonder.
- **Test Setup**:
  - The flex panel had 20 plies with a layup sequence of [45/0/-45/90/45/0/-45/90/-45/90]s. With a 50:1 scarf ratio the repair length was approximately 7.80".
  - ASTM D7264 was used as a baseline for coupon dimension and test requirements.
  - Coupon dimensions for the first attempt: 3" x 24". ASTM D7264 requires the load span to be ½ of the support span. The 4 point configuration was chosen with the aim of the loading span to fall outside of the repaired region of the coupon.

Laminate Flex Repair – Trial 1

- First attempt was made per the specification requirements of ASTM D7264.
- Parent panel size was 16” x 20” (0°).
- C-scan of initial parent panel



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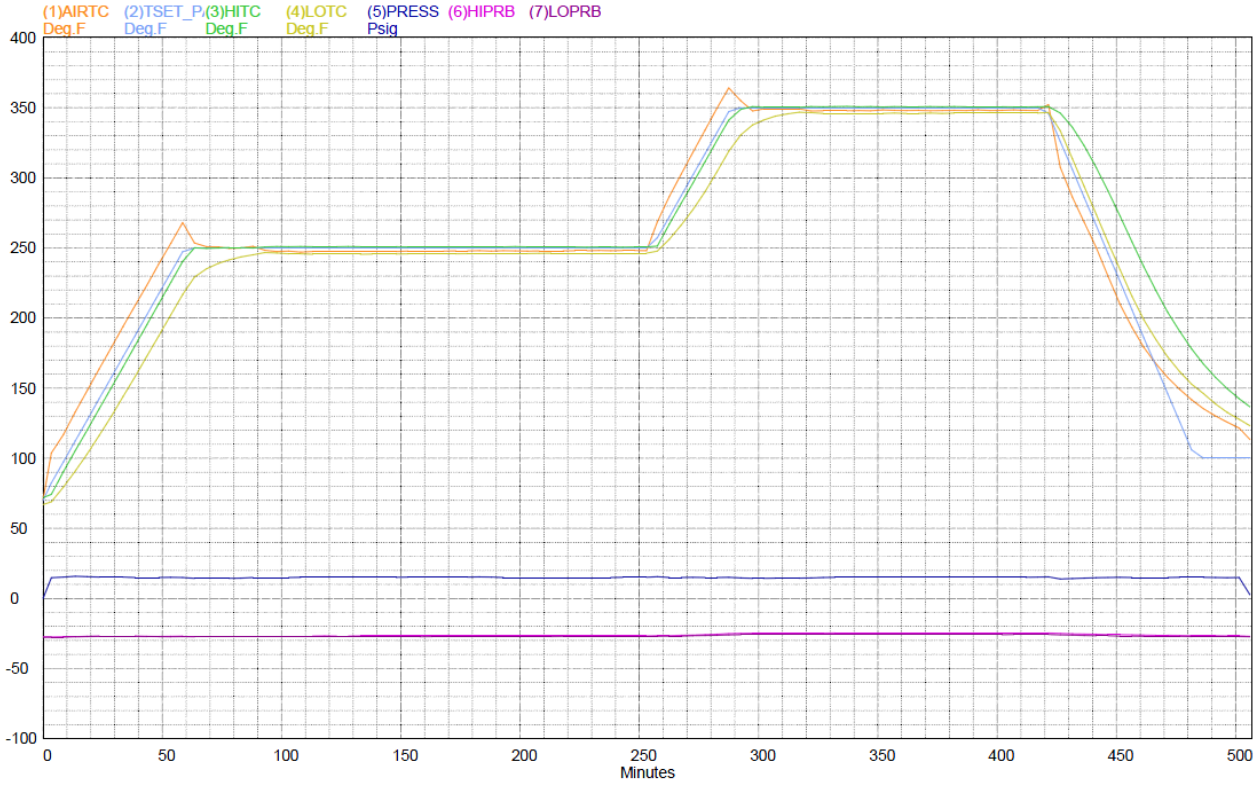
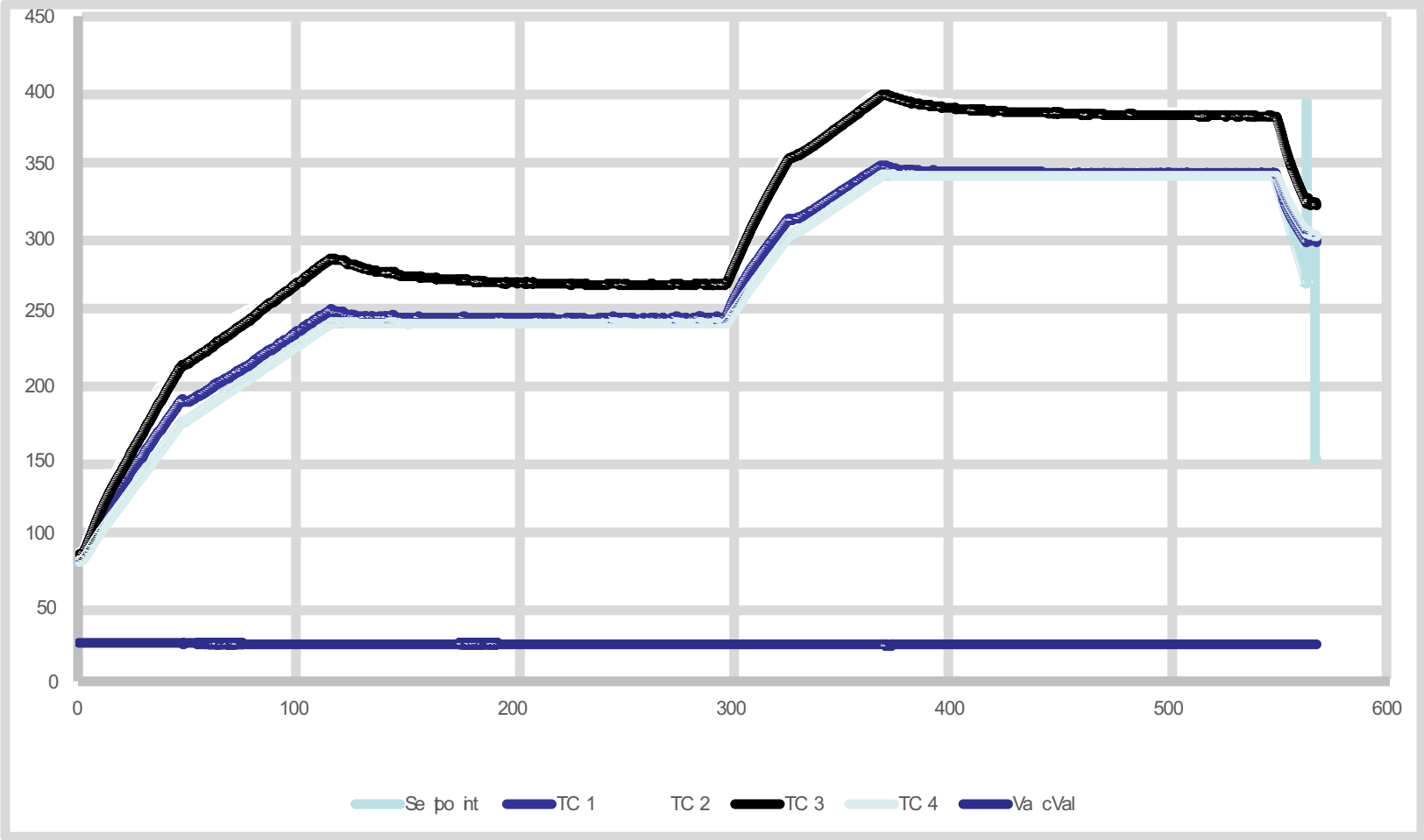
Laminate Flex Repair – Trial 1 – Parent Panel Cure Profile

CPC Control System
NCAT
Trend Report - Primary Sensors

LoadNumber:	1491	OperatorName:	KORBIN RATZLAFF
Equipment:	Econoclave 6x12	RecipeDesc:	Cycom 5320-1 30psi
Recipe Mod:	1/25/2018 2:59:33 PM	Recipe Audit #:	N/A
DataFile:	6X12_20180126-001.DAT	Report Date:	Tuesday, February 13, 2018, 4:38:50 PM
Run Start:	Friday, January 26, 2018, 8:58:09 AM	Run End:	Friday, January 26, 2018, 5:25:02 PM



Laminate Flex Repair – Trial 1 – Repair Panel Cure Profile



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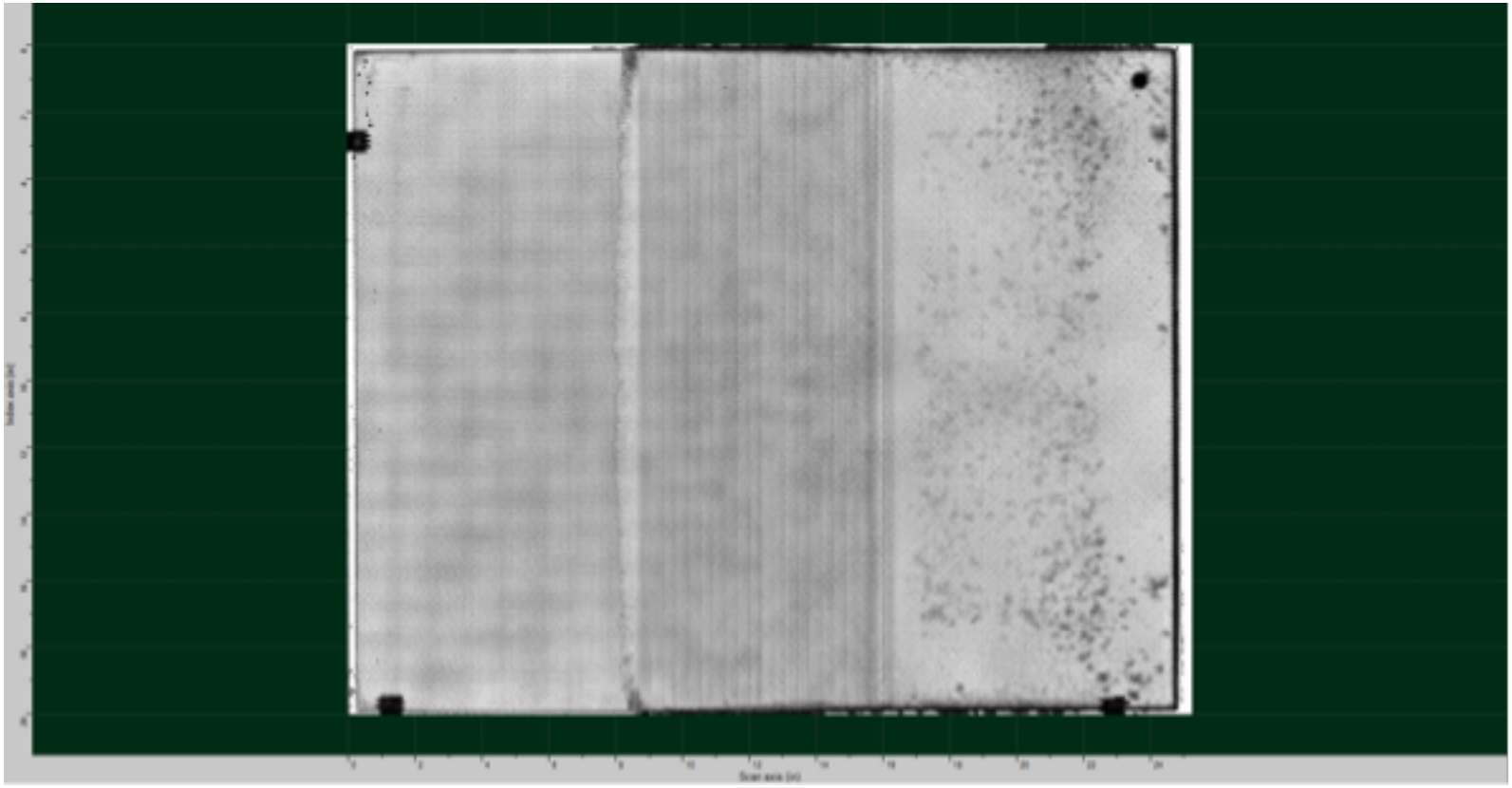
Laminate Flex Repair – Trial 1 – NDI of Repaired Panel



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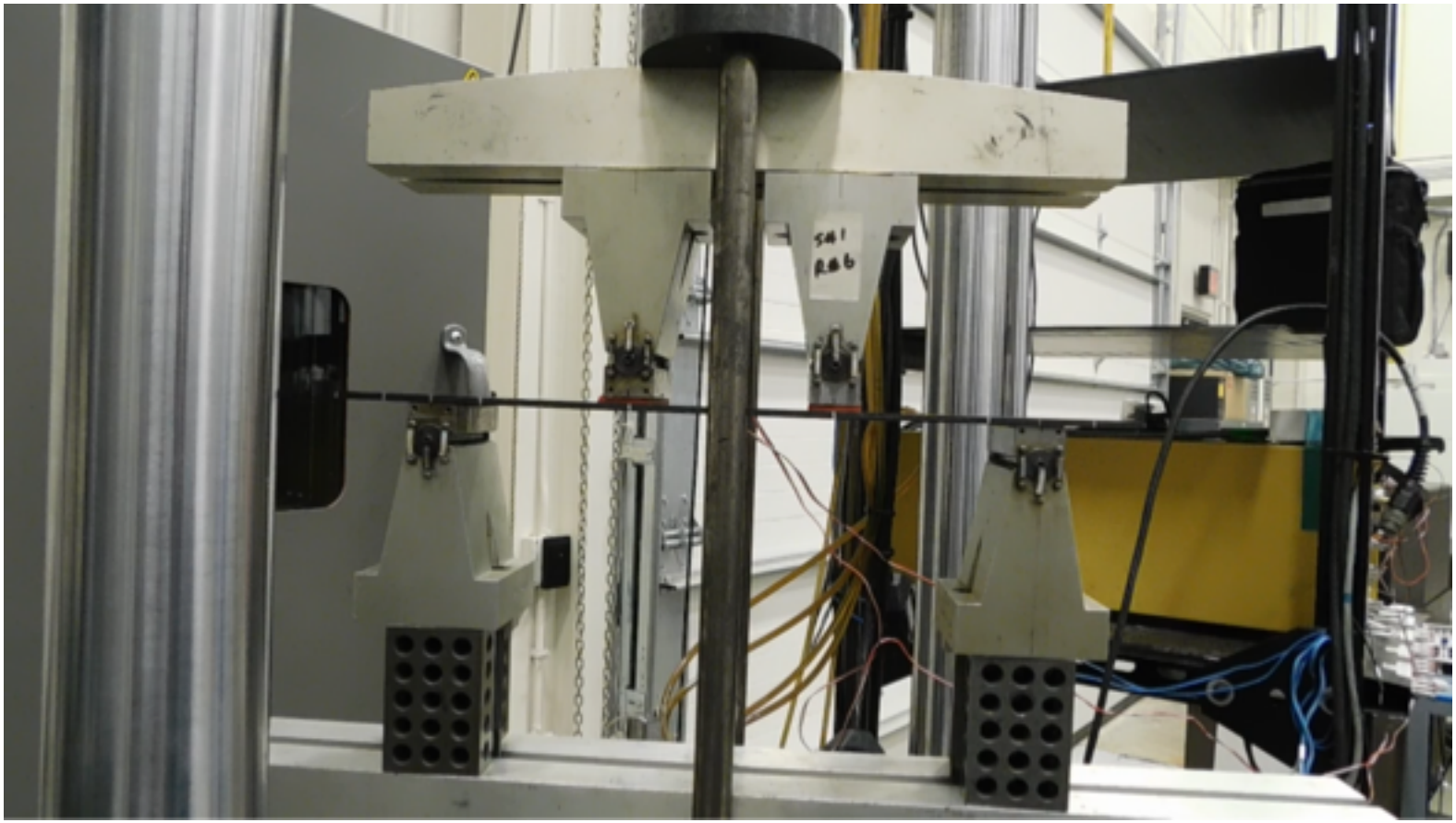
Laminate Flex Repair – Trial 1 – Test Video



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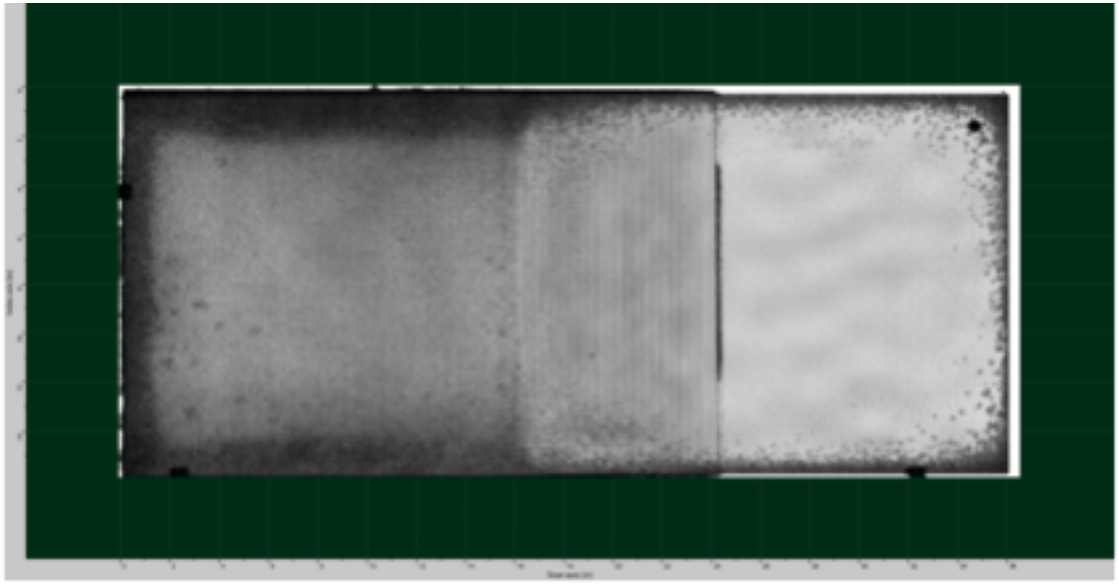
Laminate Flex Repair – Trial 1 – Test Setup and Results

- Test setup: Support span of 12” with loading spans of 4” and 6”.
- Specimens were tested with the parent side in compression.
- No strength data were obtained

- Concerns
  - Total coupon length was maxing out the test fixture
  - Loading span was not outside of the total repair region resulting in non-uniformity of the load to the repair region.

Laminate Flex Repair – Trial 2

- A much long panel was built in an attempt to bring the loading bars outside of the repair region.
- Repaired panel size was 15.5” x 36”. Parent and repair were cured using the same procedures for the trial 1 panel. Overall coupon dimensions were 3” x 35.5”



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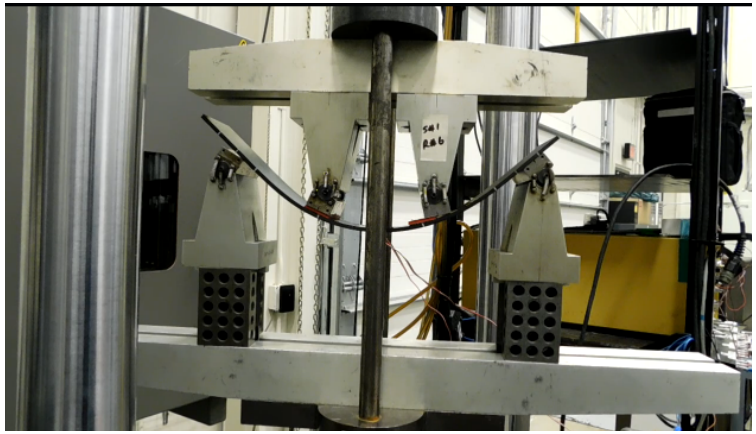
Laminate Flex Repair – Trial 2

- Support spans of 12”, 10” & 9” with loading spans of 6”, 5” & 3” were used respectively.
- An attempt to load the samples outside of the repair was made, but the coupon flexed to the point that it maxed out the fixture.
- Improper failure mode – no strengths obtained

Laminate Flex Repair - Conclusion

- Steering Committee came to the conclusion to omit the flex testing requirements from the test plan.
- No added value could be obtained from the flexural testing requirement at this time.



Qualification Repair Specific Tests (Scarf Ratio 50:1)

QUALIFICATION REQUIREMENTS	Layup	TEST METHOD	Proposed Testing									
			DRY Conditioning						WET Conditioning			
			-65F			RTD			250F			TOTAL QTY
5320-1 T650 3K PW Material/ FM300-2 Film Adhesive (50:1)		**Repaired Material Tests for Qualification**										
Tensile Tapered Joint		D8131 Tension Repair	I	II	III	I	II	III	I	II	III	
Strength [45/0/-45/90/45/0/-45/90/-45/90]S	(25/50/25)		6	6	6	6	6	6	6	6	6	54
Un-Notched Compression		D6484	I	II	III	I	II	III	I	II	III	
Strength [45/0/-45/90/45/0/-45/90/-45/90]S	(25/50/25)		6	6	6	6	6	6	6	6	6	54
Compression After Impact* **		ASTM D7136 & D7137	I	II	III	I	II	III	I	II	III	
Strength [45/0/-45/90/45/0/-45/90/-45/90]S	(25/50/25)		6	6	6	6	6	6	6	6	6	54

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Qualification Repair Specific Tests (Scarf Ratio 30:1)

QUALIFICATION REQUIREMENTS	Layup	TEST METHOD	Proposed Testing									
			DRY Conditioning						WET Conditioning			TOTAL QTY
			-65F			RTD			250F			
Tensile Tapered Joint			I	II	III	I	II	III	I	II	III	
Strength [45/0/-45/90/45/0/-45/90/-45/90]S	(25/50/25)	D8131 Tension Repair	8			8			8			24
Un-Notched Compression			I	II	III	I	II	III	I	II	III	
Strength [45/0/-45/90/45/0/-45/90/-45/90]S	(25/50/25)	D6484	8			8			8			24
Compression After Impact* **			I	II	III	I	II	III	I	II	III	
Strength [45/0/-45/90/45/0/-45/90/-45/90]S	(25/50/25)	ASTM D7136 & D7137	8			8			8			24

Note** - The 30:1 scarf ratio coupons will be tested using the equivalency protocols to gain an understanding of the difference of the 30:1 to 50:1, if a difference exists.**

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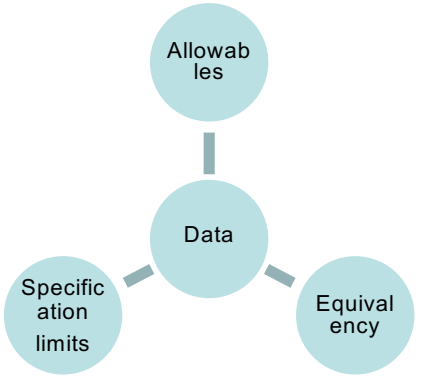
Task 4: Development of statistical guidelines

GOAL: Understanding of how parameters interact and affect variability as well as final allowables.

- Establish qualification statistical requirements. The factors affecting variability will be assessed during this task.
- Establish equivalency requirements including specification minimums for acceptance.



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Task 5: Guidelines and Recommendations

GOAL: To provide guidelines to industry for the collection of statistically meaningful critical data that designers need to utilize repair materials potentially including:

- Develop guidance for characterizing existing composite structure for repair design purposes and the application of the repair material within the design
- Expand the shared database approach to include repair material test data, material and process specifications and analysis methods.
- Development of handbook data and guidelines for CMH-17.
- Coordinate with SAE CACRC Committee

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Tasks – Based on FY2017 Deliverables

	Activity	Completion Date	Milestone / Deliverable	Completed
1.1	Survey - Develop survey questions and administer to PMC repair community - Collect survey results and analyze for input on material selection	12/15/2016	Deliverable	✓
1.2	Industry Steering Committee - Establish group of participants - Create online portal for document sharing and data repository	1/31/2017	Milestone	✓
1.3	Preliminary drafts of qualification framework - Process specification - Test plan	6/30/2017	Deliverable	✓

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Tasks – Based on FY2017 Deliverables

	Activity	Target Date	Milestone / Deliverable	Completed
1.1	Qualification Material - Prepreg delivered to NIAR (no audit required as material has previously been qualified) - Adhesive delivered to NIAR – Audit complete 2/2018	1/31/2018	Milestone	✓
1.2	Trial / Screening Studies (ongoing) - Perform flex testing studies to determine optimal configuration for qualification testing. - Present data to FAA, Industry Steering Committee, NCAMP Partners	2/28/2018	Milestone	✓
1.3	Panel Fabrication at NIAR	3/1/2018	Milestone	By 5/24
1.4	Equivalency Testing - Perform physical and mechanical testing on equivalency panels fabricated with new process specification.	6/30/2018 – CTD & RTD 9/14/2018 - ETW	Milestone	Ongoing
1.4	Qualification Testing - Perform physical and repair specific mechanical testing on qualification panels. – Generate repair test data for qualification program.	11/30/2018	Milestone	
1.4	Develop Statistical Guidelines based on qualification data	12/31/2018	Milestone	
1.5	NCAMP Reports on Qualification Data - Material technical report - Statistical analysis technical report	2/28/2019	Deliverable	
1.6	CMH-17 - Submit content, data, and protocols to Composite Materials Handbook 17 (CMH-17)	4/28/2019	Deliverable	
1.7	Final Report - Final Technical Report on the Guidelines for Polymer Matrix Composite Repair Materials	4/28/2019	Deliverable	

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Looking forward

- Benefit to Aviation
  - Understanding of repair processing limitations
  - Repeatability
  - Compare to non-repair processing of same material
  - Framework for qualification of repair tests
  - Impact of scarf ratio on mechanical properties
- Future needs
  - Establish a public research profile that documents specific inspection and surface preparation approaches for repair
  - Ability to perform repair in field and yield repeatable results
  - Standardized test methods for repair
  - Additional qualification and equivalency repair databases

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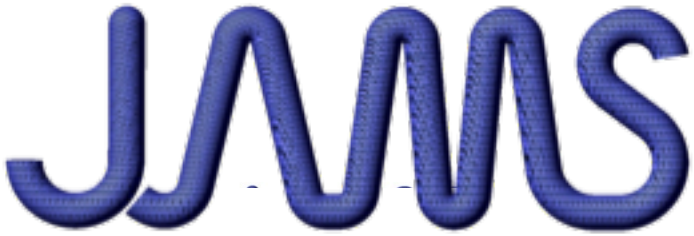
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